**PERFORMANCE EVALUATION OF SOLAR PHOTOVOLTAIC BASED MICROGRIDS**

**Synopsis of**

**Ph.D**

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## 1. INTRODUCTION

India is facing the challenge of massive increase in energy consumption for development while avoiding a catastrophic impact on the environment. With the economy growing at a rate of around eight percent a year, the demand for electricity in India is skyrocketing. To reduce the environmental pollution and minimize use of Non Renewable resources the GREEN Energy technologies have gained popularity in the Global energy scenario. Solar energy systems are one of the most widely used renewable energy generation systems with about 96.5GW installed capacity throughout the world till 2012 [1].According to IEA(International Energy Agency) solar energy generation may produce most of the world's electricity in the coming 50years, thus reducing the green house gas emissions that harm the environment.

The solar resource is virtually unlimited but the conversion of solar energy into readily usable form is inefficient and expensive to be commercially viable at present. However steps are being taken globally to make solar energy systems commercially, economically & technically viable. Furthermore, reliable solar technology needs to be complemented by energy storage system to accommodate the daily and seasonal variations in the solar radiation. The geographical location of India is quite favourable for implementation of solar energy technologies. Present solar energy utilization in India stands far from being adequate. From this perspective, India has formulated its solar energy utilization roadmap for future through Jawaharlal Nehru National Solar Mission with a target of deploying 20GW of grid connected solar power generation by 2022. In 2012, while the total yearly energy consumption was about 637GWh in India, the total theoretical PV production (including installed base capacity in 2012) was about 2.1GWh. This shows that only 0.33% of the total consumption could be supplied by the solar energy technology for the year 2012[1].

As a result there is a growing interest and initiative towards the direction of stimulating the uptake of solar energy technologies, with solar photovoltaic constituting a key technology especially in countries with high solar irradiation such as India. Addressing potential impacts of solar photovoltaic on grid operation helps in easy management of this technology [2].The energy production of a Solar Photovoltaic system primarily depends on the weather conditions of the geographical location where the system is installed and also on various other factors. Potential improvement in solar PV technologies & their installations for future expansions can only be provided by the performance evaluation & detailed outdoor field analysis of the existing solar PV systems [3]. Such evaluation is very important in enhancing the efficiency in the quest for increased power production from solar PV systems.

Conventional power plant performance metrics are difficult to apply to variable generation systems like PV generation systems [4]. Additional metrics are required from data collected from a plant over a period of time. Over the next few years when PV plants are expected to be used as a good and reliable generation system to be connected to grid, it is the need of the hour to get acquainted with the various aspects of operation and maintenance of this generation systems. Hence it is important to address the issues of operation & balancing the grid with variable resources.

## 2. Solar Power Technologies

Among various renewable energy resources, India possesses a very large solar resource. Solar Potential in India is about 20-30 MW/sq km (i.e.>100 GW). India being a tropical country has longer hours of sun availability with high solar intensity per day and therefore solar energy in India has great potential as future energy source. The 3-phase approach of the JNNSM – Jawaharlal Nehru Solar Mission which spans from 2012-2022 has set a target of deploying 20GW of grid connected solar power and also reduce the cost of solar power generation by achieving various objectives set for the period(2012-2022)[5].

Solar power technologies are divided into various techniques of energy conversion as follows

a) Solar Photovoltaic - Non Concentrated(SPV)
b) Concentrated Solar Power(CSP)
c) Concentrated Photovoltaic(CPV)
d) Dye sensitized Solar Cell(DSSC)
e) Solar Thermoelectricity System(STS)

Generally SPV and CSP are the two most mature technologies. They have been commercialized and are expected to experience rapid growth in the future. Though CPV can achieve highest efficiency of all the technologies, but instability in generation and storage due to various factors like weather variations etc. make it unreliable. DSSC technology has lower efficiency compared to traditional semiconductor solar cell. This has been one of the many drawbacks of DSSC that prevent its mass production and wide use of this technology.In STS, the cost of raw materials is too expensive and they purely depend on direct radiation only. However other technologies listed above can also be commercially implemented if certain technology breakthroughs are made in the near future with their existing advantages.

Solar Photovoltaic Systems

Solar Photovoltaic (SPV) cells generate electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of solar cells. Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide. Photovoltaic solar panel is the most commonly used solar technology to generate electrical energy. SPV power plants are being used in variety of configurations viz.

- Grid Connected SPV system without Battery Storage
- Standalone SPV system with Battery storage
- Standalone with Grid Connected SPV system with storage

Concentrated Solar Power Systems

Concentrated solar power systems use mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Electrical power is produced when the concentrated light is converted to heat which drives a heat engine (usually a steam turbine) connected to an electrical power generator. Unlike the photovoltaic solar cells, converting energy from sunlight to electricity by CSP systems is based on the application of heat effect rather than photovoltaic effect which directly transforms photon energy into electrical energy.

Photovoltaic devices are rugged and simple in design requiring very little maintenance and their biggest advantage being their construction as stand-alone systems to give outputs from microwatts to megawatts [6]. Solar-to-electricity efficiencies of up to about 25 percent can be delivered while solar-based Brayton cycles offer solar-to-electricity efficiency could be as high as 35 percent. CSP systems with the same size solar field (collecting area) as PV systems are expected to produce more energy each year under same environmental conditions [7].

The life of photovoltaic panel is expected to be 25 years. While the CSP systems have better performance, their lifespan is approximately 25 to 30 years. The Life Cycle Assessment results show that

PV technologies are already proved to be very sustainable and environmental-friendly in the state of the art [8].

Compared with PV systems, CSP requires higher capital investment and maintenance cost. An advantage of photovoltaic panels is that they are able to collect both direct and diffused irradiations, so the technology can work even on cloudy days. Variations in solar radiation and ambient temperature daily, monthly & yearly influence the performance of plant [9]. Approximately 13-16% percent of the incident radiation is captured when the sun is high in the sky, depending on the amount of dust and haze in the atmosphere [10].

Power grids usually prefer CSPs over PVs. PVs are more suitable than CSP for off-grid applications. They do not have moving parts and work quietly, which means maintenance cost will be much less. PV technology is already competitive today in selected off-grid applications [10].

With vast number of applications, the demand for solar photovoltaics is increasing day by day [6]. Though the installed capacity of grid-connected photovoltaic (PV) power system installations has grown dramatically over the last decade, the capacity is still less than 1% of the peak load on the utility grid, but at this growth rate, a 5% or 10% level may be less than a decade away.

**Grid-connected PV** power system designs focus on converting as much solar power as possible into real power (current flowing into the grid in phase with the utility-defined voltage). This design goal is appropriate for a technology that has insufficient installed capacity to approach the typical loads supplied by the electric power utility infrastructure. However, as the capacity of this technology grows, this assumption will at some point no longer hold true and PV power systems will be required to provide increasing levels of grid support services and to participate to a greater extent in utility dispatch and operations processes.

**Stand-alone PV** systems must regulate their generation to match the load and maintain power balance. Battery energy storage is usually included to address power demand surges, store generated power during low demand, and continue to supply power to the load during cloudy or night time conditions [11]. The technology is available to incorporate similar features into grid-tied PV inverters, but doing so would drive up the cost of PV electric power compared to real-power-optimized grid-connected PV power systems.

## 3. Need for Performance analysis

To see India as SOLAR INDIA as stated in JNNSM, it is important to focus on setting up an enabling environment for solar energy penetration in the country[5].Taking into account the initial experience, capacity is needed to be aggressively ramped up to create conditions for up scaled and competitive solar energy penetration in the country [12].

Over the last decade there has been significant rise in the PV electrification projects both grid-connected and Stand-alone. Unfortunately many systems are not able to meet the expectations of end-users and also fail to attain their life expectancy [13]. Thus they fall short of their intended aim. Long term monitoring of solar PV systems, to analyze their detailed performance over time and local seasonal shifts is a recent development in many countries. This vital information is essential to understand a systems actual field performance. This leads to more appropriate system design, considering the local context in regard to the prevailing meteorological conditions and energy service demands [14]. This data can improve system design and their long term sustainability.

It is clear from the above discussion that solar energy is becoming an important source of energy all over the World and especially in India. Very few solar plants have been installed in India so far, and therefore minimum historical experience is available [15]-[22]. It is important to investigate the performance of solar power plants and Knowledge about the performance of solar power plants will result in correct investment decisions, a better regulatory framework and favourable government policies. Critical factor for continuous development of PV in India is its accuracy and consistency in monitoring and evaluating performance of existing PV systems. These are key metrics for identifying future needs [9].

## 4. SPV Microgrid at Dayalbagh Educational Institute

Dayalbagh Educational Institute is a unique university which is a pioneer in green energy initiative, environment protection and energy sufficiency. On a clear day, the whole university campus is completely powered by solar power plants. The project started in March 2010 and the commissioning completed in December 2011 at a cost of Rs. 11,15,38,000.00. There are seven solar electric power plants at Dayalbagh Educational Institute. The locations and capacities of the power

plants are given in the following table (Fig 1: a satellite view of six of the seven plants installed and their coverage).

*Fig 1 : Satellite view of the institute showing six of the seven existing plants and their coverage*

| Sl. No. | Site | SPV Capacity |
|---|---|---|
| 1 | Faculty of Engineering | 147.8 kWp |
| 2 | Faculty of Science | 148.32 kWp |
| 3 | Faculty of Arts | 40.8 kWp |
| 4 | Faculty of Education | 40.8 kWp |
| 5 | Faculty of Social Science | 40.8 kWp |
| 6 | USIC Complex | 94.68 kWp |
| 7 | Boys Hostel | 5 kWp |

All the power plants are Hybrid PV Power Systems, primarily intended to power independent localized loads as well as to export excess PV power to grid. The three phase DSP based, Grid Support Conditioners (GSC) (Fig 2) are designed to operate as a multi-function power conditioning unit combining the functionality of a grid interface solar inverter with a true on line single conversion UPS. The GSC system allows the option of combining renewable energy sources on priority with the functionality of an industrial UPS system. Based on the Solar power available, connected load and battery state of charge, the unit configures itself as either a charger or inverter and can start an optional back up Diesel Generator, if the battery reserve cannot be maintained by the Solar power and there is loss of grid power. In charging mode the system maintains the battery voltage at a user specified value and charges the battery in accordance with standard procedures, thus maximizing the life of the battery bank. The DSP based

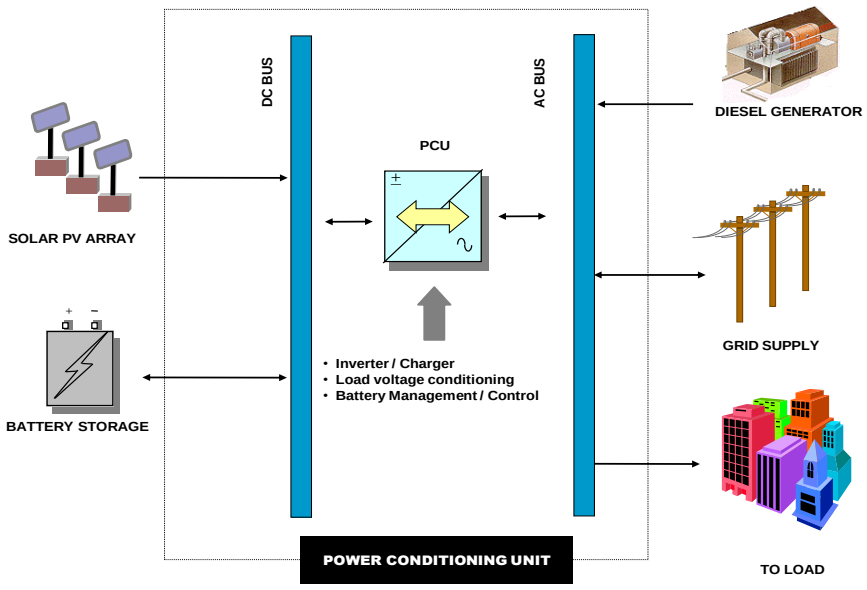


*Fig 2: Grid Support Conditioner System*

GSC provides output voltage conditioning when operating in a grid interactive mode and has the ability to export excess Solar power to the grid.

In this study, we propose to evaluate the performance of 520 KWp PV systems installed in Dayalbagh Educational Institute, AGRA, India and analyze not only from component perspective but also location and global perspective by analyzing results of one year of monitoring. The effect of various factors contributing to the performance of solar power plants such as irradiance, temperature and other climatic conditions, design, system efficiency and degradation due to aging etc will also be analyzed.

## 5. State of the Art - Current Practices

In late 80's, Performance Monitoring, Evaluation & Analysis of a PV system has gained importance giving way to new Standards & Procedures for whole process. This has introduced IEC 61724:1998 – Photovoltaic system performance monitoring Guidelines for measurement, data exchange and analysis [23]. This standard describes general guidelines for the monitoring and analysis of the electrical performance of PV systems. This standard recommends procedures for monitoring of energy related PV system characteristics such as in-plane irradiance, array output, storage input and output, power conditioner input and output for the exchange and analysis of monitored data and to assess the overall performance of PV systems both stand-alone and grid-connected. Since then researchers in many countries have authored publications providing basis for intensive research in this field.

L. Moore *et.al.* [24] have described their 5-year experience of 4.9MW PV plant at Arizona public service, AZ. It was observed that compared to fixed latitude systems, energy production was 23% and 37% higher for horizontal and tilted tracking respectively. Average annual O & M cost is 0.35% of the initial system cost.

L.Moore *et.al.* [25] have also presented 5-year experience of 5MW PV plant at Tuscan Electric Power, Tuscan, AZ. This paper presents an assessment of operating experience including performance, costs, maintenance and plant operation over 5-year period. Annual average capacity factor for all systems over the period was 19.5%. Average annual O & M cost is 0.12% of initial system cost. The mean time between unscheduled maintenance events per system is 7.7 months of operation.

U. Jahn *et.al.* [26] presented operational performance results of grid-connected PV systems in Germany. Performance of 235 PV installations in Germany and 133 PV installations in other countries were

compared and discussed. Older installations were found to be on lower side of energy yield with average mean of performance ratio as 0.65 and the newer installations had an average mean performance ratio as 0.74. For Germany, a significant rise in PV system performance was observed for new PV installations due to higher component efficiencies and increased availabilities. Dominating performance constraints were poor reliability of inverters, long repair times and shading problems.

U. Jahn *et.al.* [27] presented results of performance of 334 PV installations across 14 different countries. Switzerland showed a higher PR (>0.80). For Japan, lessons were learnt from monitoring programs and performance improvement was observed. It was observed that system availability indirectly indicates the reliability of the system. In the same way Performance Ratio also is affected by the reliability. Low PR was due to high failure rate. It was further observed that the system availability is generally higher for systems which are intensively monitored.

O saheed Ismail *et.al.* [28] presented the performance assessment of installed PV of Oke-Agunla in Nigeria. The result showed that only 14.52% of 4.5KW installed for a village of 150 households was utilized. This under utilization was because of poor maintenance, system malfunctioning, lack of technical know-how and inadequate training of village personnel causing an inefficient PV systems operation.

J.D.Mondol *et.al.* [29] presented the impact of array inclination and orientation on the performance of PV plant. Incident insolation and PV outputs were maximum for surfaces inclined at $30^{o}$ due south and minimum for surfaces at $90^{o}$. For horizontal surface monthly variations in the system parameters were significant over a year. TRNSYS simulation package was used to validate the above results.

Eltawil.M *et.al.* [30] emphasized the importance of grid connected PV systems regarding the intermittent nature of renewable generation. A review on expected potential problems associated with high penetration levels was presented. The need for reliability, life span and maintenance needs during long term operation of PV system was reviewed.

R. Hosseini *et.al.* [31] presented the improved performance of PV system by improving the constraints like reflection of sun's irradiation and temperature of PV modules and hence increasing the electrical efficiency by 33% by decreasing the module temperature by $18^{o}$.

Lacour Ayompe *et.al.* [32] presented the results of performance of 1.72KWp PV system in Ireland monitored in 2008-2009. Performance parameters like average solar insolation, ambient temperature, PV module temperature, wind speed were analyzed. In addition to these final yield, array yield, reference yield, performance ratio, capacity factor, module and system efficiencies, various losses were detailed appropriately.

P. Perez Higueras *et.al.* [33] presented the experience of PV systems installed at University of Jaen. Parameters like ambient temperature, in-plane radiance, array voltage, array current, inverter power output were monitored for 9.6KWp PV system. A special mention was made and comparison was shown between campus consumption and PV generation. Parameters like Final yield, Array yield, reference yield, Performance ratio, system losses etc were derived from the analysis.

A.S. Elhodeiby *et.al.* [34] presented performance analysis of 3.6KW thin film Rooftop grid-connected PV system in Egypt. Monthly, Daily, Annual performance parameters like capacity factor, availability factor, solar irradiation, power output, system efficiency, Performance ratio are monitored and derived. The results showed that it was highly imperative to develop evaluation, analysis of PV systems in Egypt.

Tiwari G.N *et.al.* [35] presented a detailed method to analyze the energy pay-back time and green house gas emissions of a 1.2KWp PV installation at IIT Delhi. The effect of insolation, overall efficiency, lifetime of PV system on energy pay-back time and green house gas emissions have been studied with and without Balance of System(BOS).

## 6. Gaps

It is clear from the above state of the art that active research is in progress across the globe in order to effectively utilize the solar power as a future energy source. In spite of strenuous efforts made, it is found that there are few areas as discussed below where improvement is still needed.

**Geographical location based performance analysis:** Though active research is going on around the world, such studies pertaining to Indian geography(locations) has been a very few in number and hence to achieve the target of National Solar Mission of India(JNNSM), it is imperative that countries like India needs such location based studies where solar resource is abundant.

**Performance of stand-alone with grid-connected systems:** Most of the PV systems studied have been either stand-alone or grid-connected systems and study of a stand-alone system with grid-connected has been a rare phenomena.

**Investigation of effects of various factors on plant performance:** A performance study including the effects of various parameters on plant performance particularly in Indian perspective is the need of the hour.

**Design of new performance indices:** There is always room for introduction of new performance indices during the course of performance analysis of a stand-alone with grid-connected system. This can initiate a new area of research in the performance analysis of a PV plant.

## 7. Proposed work

### a) Performance analysis of PV plant at an Indian location based on IEC 61724 standards

A stand-alone with grid-connected PV system of 515KWp located at DEI, Dayalbagh, AGRA has been considered for the proposed study of performance analysis based on IEC 61724 standards. Analysis is proposed on an annual basis where in various performance indices like Array Yield, Reference Yield, Performance Ratio, Capacity factor annually are derived.

### b) Design of new performance indices

Since the sample site selected for the study is a new Stand-alone with grid-connected PV system, the intent of design of new performance indices is to provide a performance summary suitable for comparing PV installations of different sizes, operating in different locations and proving energy for different uses, in such a way that the relative merits of different indices (both old and new) become evident.

### c) Investigate the effect of various factors on plant performance

Effects of various parameters like ambient temperature, module temperature, wind speed, irradiance, dust, partial shadow, module efficiency, system efficiency, inverter efficiency, energy losses etc on the PV plant performance can be studied in Indian perspective.

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